(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 200 333 A2**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 86302043.4

(22) Date of filing: 19.03.86

(51) Int. Cl.4: H01J 37/02, H01J 37/304, H01J 37/305

(30) Priority: 24.04.85 US 726713

(43) Date of publication of application: 10.12.86 Bulletin 86/45

(84) Designated Contracting States: DE FR GB NL

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(54) Ion beam processing method and apparatus.

(57) An ion beam processing apparatus which makes possible the precise sputter etching of insulating and other targets (16), using a finely focused beam of ions (14) produced from an ion source (11) includes a beam of electrons (21) directed onto the target - (16) which neutralizes the charge created by the incident ion beam (14). Ultra-precise control of the etching process is achieved by monitoring (24, 26) the particles that are sputtered from the target surface (15).

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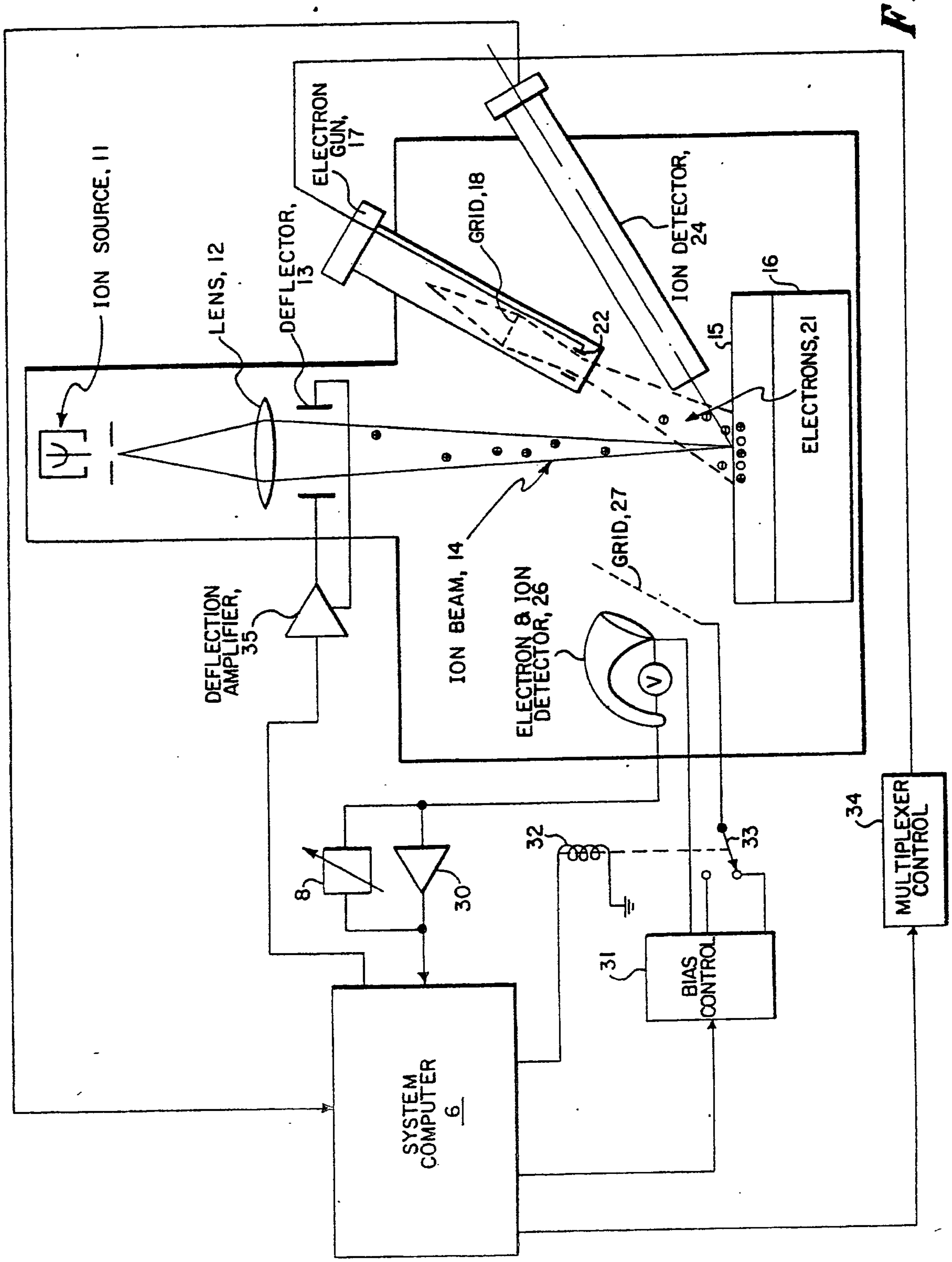
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Fig. 1

Ion Beam Processing Method and Apparatus

The present invention relates to an ion beam processing method and apparatus and more particularly concerns the use of a submicron focused ion beam to sputter etch targets that are nonconductors in a precise and highly controlled manner. This invention provides a way of repairing optical and ion projection masks, and x-ray lithography masks and reticles.

The principle technical difficulty which arises in etching insulators is associated with the inability of these insulators to drain the charge that is deposited by an ion beam during the etching process. The local potential may reach nearly the potential of the incident beam and if this occurs it seriously degrades the beam shape. The beam position is then no longer a reliable function of the electronic driving signals.

A search has uncovered the following patent specifications US-A-3,219,817, US-A-3,665,185, US-A-3,845,305, US-A-3,878,392, US-A-4,052,614, US-A-4,249,077, US-A-4,381,453, GB-A-999,380 and a publication of Helmut Liebl entitled "Design of a Combined Ion and Electron Microprobe Apparatus" in Int. J. Mass. Spesctrom. Ion Phys., 6 Nos. 5-6 (1971), pp. 401-412. Other prior art found includes US-A-3,665,185, US-A-3,920,989, US-A-4,249,077, US-A-4,361,762, US-A-4,447,724, US-A-4,463,255, US-A-4,453,078, US-A-3,920,989, US-A-4,249,077, US-A-4,361,762 and US-A-4,447,724. The most pertinent of these is believed to be US-A-4,463,255 which identifies electron flooding as a known technique for charge neutralization.

According to this invention an ion beam processing apparatus comprising,

an ion beam source, and

an electron beam source,

is characterised in that the ion beam source includes means to provide a finely focused ion beam for impingement at a point upon a substrate surface in a predetermined surface plane,

and in that the electron beam source includes means for directing the electron beam towards the surface plane in a region embracing and surrounding the said point in the surface plane impinged upon by the ion beam, the electron beam neutralizing any surface charge in the surface plane caused by the ion beam so that defocusing and deflection of the ion beam in the surface plane by such a charge build up is reduced.

It is preferred that means are provided for monitoring particles sputtered from the target surface to control the process of etching the target.

A particular example of a method and apparatus in accordance with this invention will now be described with reference to the accompanying drawings; in which:-

Figure 1 is a block diagram of a system according to the invention; and,

Figure 2 is a schematic representation of the etching process according to the invention.

The system includes an ion source 11 providing ions focused by a lens 12 to form a finally focused ion beam 14 that is deflected by deflecting plates 13 to impinge upon surface 15 of substrate 16. A low energy electron gun 17 has an electron source focused by lens 18 to form a beam of electrons 21 that may pass through control elements 22 to form a focused spot of electrons that bathe a portion of surface 15 surrounding the point where ion beam 14 is sharply focused upon surface 15. Control element 22 may receive signals through multiplexer control 34 for deflecting or blanking the flooding electron beam.

An ion detector 24 detects ions sputtered from surface 15 to provide a signal to system computer 25. Electron and ion detector 26 may detect electrons and ions sputtered from surface 15 through grid 27 when grid 27 is appropriately biased to provide a signal through operational amplifier 31 that is also applied to system computer 25. System computer 25 controls bias control 31 and relay 32 connected to its arm 33 to selectively connect grid 27 to ion selective or electron selective potentials provided on correspondingly designated terminals of bias control 31. Typical electron and ion selective potentials are within the ranges of +300 to +600 volts and -300 to -2000 volts, respectively. Multiplexer control 34 may provide a deflection signal to deflection plates 22 of electron gun 17. System computer 25 may also provide a deflection signal to deflection amplifier 35 that energizes deflection plates 13.

The components of the system are known in the art and not described in detail herein to avoid obscuring the principles of the invention. For example, the ion source 11 my be one commercially available from FEI Company of Beaverton, Oregon. the low energy electron gun 17 may be one commercially available from Kimball Physics of Wilton,

N. H. the electron and ion detector 26 may comprise a channel electron multiplier commercially available from Galileo of Sturbridge, Massachusetts.

Having described the system arrangement, its mode of operation will be described. The system of FIG. 1 is useful in imaging, neutralizing ion charge and detecting the end point of a sputtering process. To this end ion beam 14 originates from a liquid metal ion source 11 providing ions that are accelerated and focused by electrostatic lens 12. Deflector 13 may precisely position ion beam 14 over a field of view on surface 15 typically approximately one square millimeter in area.

When ion beam 14 impinges upon surface 15 of substrate 16, a number of events occur.

(1) Low energy secondary electrons are generated.

(2) Positive and negative low energy secondary ions are generated.

(3) Atoms are sputtered away from surface 15.

(4) Primary ions from beam 14 are implanted into surface 15.

Referring to FIG. 2, there is shown a schematic representation of these processes. Each particle so generated comes only from the area directly beneath ion beam 14; hence, it is important that beam 14 be kept small and precisely located where it meets surface 15. If substrate 16 is not a conductor, a typical occurrence when etching on a semiconductor or insulating surface, the incident ion charge builds up under the beam and creates an electric defocusing field that interferes not only with the ion beam shape at the surface, but also the trajectories of ions and electrons as they leave the surface. A potential of only a few volts seriously degrades these processes. In the apparatus of FIG. 1, both electrons and ions are used to provide precise topological and compositional information relating to the surface under the focused ion beam 14. This information is useful for both surface imaging and determining the rates of sputtering.

By bathing the surface 15 around the point of impact from ion beam 14 with electron gun 17, these electrons neutralize the positive charge of the incident ions and thereby reduce the undesired defocusing field.

Multiplexer control 34 responds to signals from system computer 25 to provide a signal on electron gun control electrodes 22 that effectively controls the number of electrons on surface 15 so as to maintain sufficient low energy electrons to establish the desired neutralization. Switchable negative ion and electron detector 26 measures the number of electrons or ions escaping from surface 15 when grid 27 is biased to allow passage of them to provide electrical signals amplified by operational amplifier 31 of adjustable gain to provide an appropriate signal to system computer 25. Computer system 25 monitors these detected signals to control the electron current and timing such that the processes are as unperturbed as practical. By adjusting the electron flow upon surface 15 to neutralize the positive ion charge from beam 14, the processes remain free of disturbances caused by a charged surface.

While the system has been described in association with a system computer that may exercise control in accordance with known techniques, the invention could be practiced exercising the desired control manually. For example, deflection signals could be applied to deflector 13 manually by operating suitable potentiometers, relay 32 could be operated manually to switch between detecting for electrons and ions, and visual indicators, such as meters, could be placed at the output of operational amplifier 31 and scanning ion mass detector 24. The control signals applied to control element 22 could be manually controlled.

Furthermore, instead of displacing ion beam 14 by applying signals to deflector 13, ion beam 14 could remain stationary, and substrate 16 displaced. Substrate 16 could be supported on a mechanical stage, preferably having precision mechanical displacement mechanisms for displacement in mutually orthogonal directions between positions that can be readiliy determined to facilitate identifying the position where a feature is indicated, typicaly by a sharp change in detected ion and/or electron current.

Preferably the deflection signals applied to deflector 13 are correlated with the signals received from channel electron multiplier 26 so that a sudden change in detected electron and/or ion current is associated with particular deflection signal amplitudes that correspond to particular locations on the substrate surface 15.

The invention is especially useful in repairing photooptical masks and reticles. Because large areas of the mask or reticle are highly insulating glass, these surfaces are subject to charge accumulation when bombarded by positive ions. The invention neutralizes this charge accumulation.

The invention may be used for opaque repair - (etching of light blocking particles), transparent repair (making transmitting areas opaque) and imaging (so that defective areas can be precisely lo-

cated with respect to the ion beam and other features of the substrate being repaired). All of these operations are enhanced by using the invention to neutralize charge accumulation and facilitate the process. Consider the following examples.

In the opaque repair process, the ion beam is used to sputter away the defect-forming material. Electron charge neutralization is used both in real time and in a multiplexed mode so that both ion imaging and secondary electron imaging may be used to locate the defect and monitor the sputtering process. For example, when the secondary electrons are being used to produce the desired image, the low energy flood electrons in beam 21 are attracted to detector 26 overloading the desired signal. Hence, depending on the conditions, electron gun 17 is switched on and off in a time division multiplexed way in cooperation with the primary ion beam 14 to simultaneously permit charge neutralization and secondary electron imaging.

For positive ion imaging (used to produce different types of contrast) the electron neutralizer is used concurrently with the primary ion beam 14. This approach is successful because the bias from bias control 13 to grid 27 when relay 32 is operated rejects the negatively charged low energy electrons of the neutralizing beam 21 while accepting secondarily emitted positive ions.

In the repair of opaque defects SIM detector 24 is used to quantitatively determine the types of ions leaving substrate 16. This information is processed by system computer 25 to adjust the etching location of beam 14 to minimize undesired etching of substrate 16, typically glass. Electron neutralization is used during this process in real time in a way analogous to the method of secondary ion imaging described above.

In clear repair the preferred method of producing opaque areas in the glass is to etch various types of optical diffusers as described in a paper by A. Wagner, D. Barr, D. Atwood and J. H. Bruning presented at the seventeen Electronic, Ion and Photo Beam Symposium in Los Angeles, California, in May 1983. This process requires precise and relatively long time etching of the insulating glass surface. Since precise optical elements must be etched, the electron neutralizing beam 21 is concentrated at the area of the ion etching beam 14.

It is advantageous to use ion beam induced conductivity to assist in charge neutralization. As ion beam 14 is scanned over surface 15, sufficient crystal damage and impurity implanatation occurs to produce a thin conductive layer in the upper 10 nanometers of the previously insulating glass substrate 16. This conductive layer does not disturb the desirable optical characteristic of the glass while providing an increased surface conducting area for flood electrons to reach the area of primary ion beam etching. Thus, it is unnecessary to finally focus electron flood beam 21, and a neutralizing beam may be used having a current density much less than that of primary ion beam 14. The ion beam current is typically 0.5×10^{-9} amps with a density of about 1 amp/cm². The electron beam current is typically 10^{-6} amps with a current density 10^{-4} amps/cm². The electron beam current is much greater and its current density much less than the current and current density, respectively of the finely focused ion beam.

Claims

1. An ion beam processing apparatus comprising,

an ion beam source (11), and

an electron beam source (17),

characterised in that the ion beam source (11) includes means (12, 13) to provide a finely focused ion beam (14) for impingement at a point upon a substrate surface (15) in a predetermined surface plane,

and in that the electron beam source (17) includes means (18, 22) for directing the electron beam (21) towards the surface plane (15) in a region embracing and surrounding the said point in the surface plane impinged upon by the ion beam (14), the electron beam (21) neutralizing any surface charge in the surface plane (15) caused by the ion beam (14) so that defocusing and deflection of the ion beam (14) in the surface plane (15) by such a charge build up is reduced.

2. Ion beam processing apparatus according to claim 1, further comprising,

detecting means (24, 26) for sensing secondarily emitted particles from the surface plane,

and control means (6) responsive to signals provided by the detecting means (24, 26) for controlling the ion beam source (11) and the electron beam source (17) to coact and cause the ion beam (14) to etch the surface plane (15) in a required manner and at a required location.

3. Ion beam processing apparatus according to claim 2, wherein the detecting means comprises a

secondary ion mass detector (24) for sensing the types of ions leaving the substrate (16) in response to impingement on the substrate surface (15) by the ion beam (14).

4. Ion beam processing apparatus according to claim 2, wherein the detecting means comprises an electron and ion detector (26) for detecting electrons and ions secondarily emitted from the surface (15) of the substrate (16) in response to impingement by the ion beam (14).

5. Ion beam processing apparatus according to claim 4, and further comprising grid means (27) interposed between the electron and ion detector - (26) and the surface plane (15) for selectively establishing an electric field that prevents electrons from entering said electron and ion detector (26) whilst allowing ions to enter,

and means (31) for selectively biasing the grid means (27) to establish the electric field.

6. Ion beam processing apparatus according to claim 5, further comprising,

multiplexer control means (34) for controlling the times when the ion source (11) and the electron source (17) operate to provide ion (14) and electron (21) beams impinging upon the surface plane (15) so that they impinge during mutually exclusive time intervals.

7. Ion beam processing apparatus according to claim 1, wherein the electron beam source (17) produces current and a current density which is much greater and less respectively than that of the ion beam source (11).

8. Ion beam processing apparatus according to claim 1, wherein the substrate (16) having the surface (15) in the predetermined surface plane is made predominantly of insulating material and responds to impingement of the ion beam (14) by developing a thin conductive layer in its surface - (15),

the conducting surface presenting an increased surface conducting area for electrons from the electron beam source (17) to reach the said point of primary ion beam etching on the surface (15) to neutralize the charge at it.

9. A method of using an ion beam processing apparatus in accordance with any one of the preceding claims, including the steps of:-

directing a finely focused ion beam (14) upon a substrate surface (15) at a point in a predetermined surface plane, and

directing an electron beam (21) towards the surface plane (15) in a region embracing the said point in the surface plane impinged upon by the ion beam - (14), the electron beam (21) neutralizing any surface charge in the surface plane (15) caused by the ion beam (14), so that defocusing and deflection of the ion beam (14) in the surface plane (15) by such a charge build up is reduced.

10. A method according to claim 9, further including the steps of:

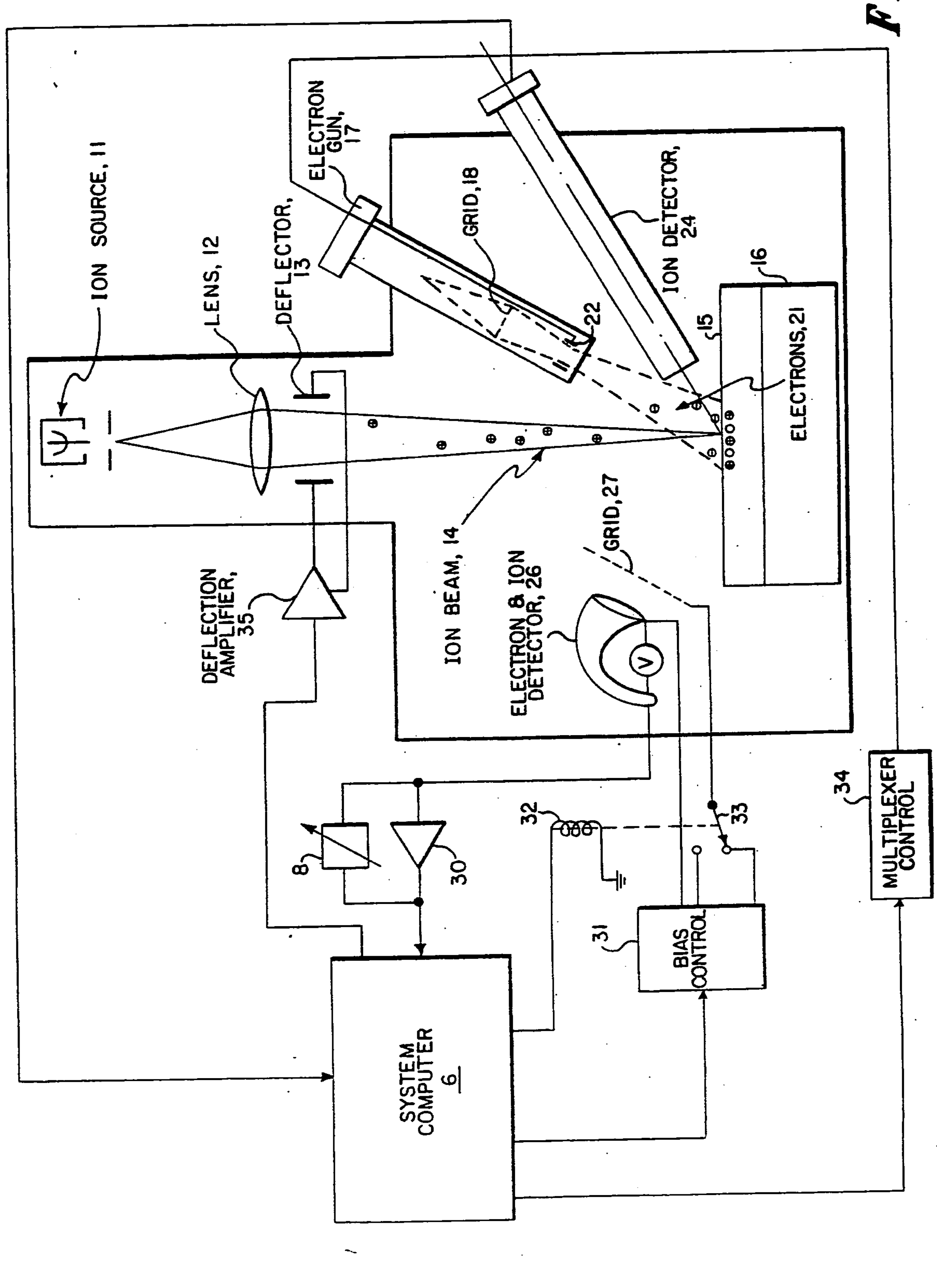
sensing secondarily emitted particles from the surface plane (15) in response to impingement of the ion beam (14) upon it to sense characteristics of the surface, and

positioning the ion beam to etch at a predetermined location which is identified by observing a change in the density of particles emitted from the surface as the ion beam (14) and the surface (15) are displaced relative to one another.

11. A method according to claim 10, in which both secondarily emitted electrons and ions emitted from the surface in response to impingement by the ion beam (14) are sensed.

12. A method according to claim 9, 10 or 11, further including the step of:

damaging the surface (15) of the substrate (16) and implanting impurities therein with the ion beam - (14) to produce a thin conductive layer substantially in the upper 10 nanometers of the substrate to provide an increased surface conducting area for electrons from the electron beam (21) to reach the said point of primary ion impingement upon the surface (15) without disturbing desirable optical characteristics of the substrate (16).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BIAS CONTROL
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MULTIPLEXER CONTROL
SYSTEM COMPUTER
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Fig. 1

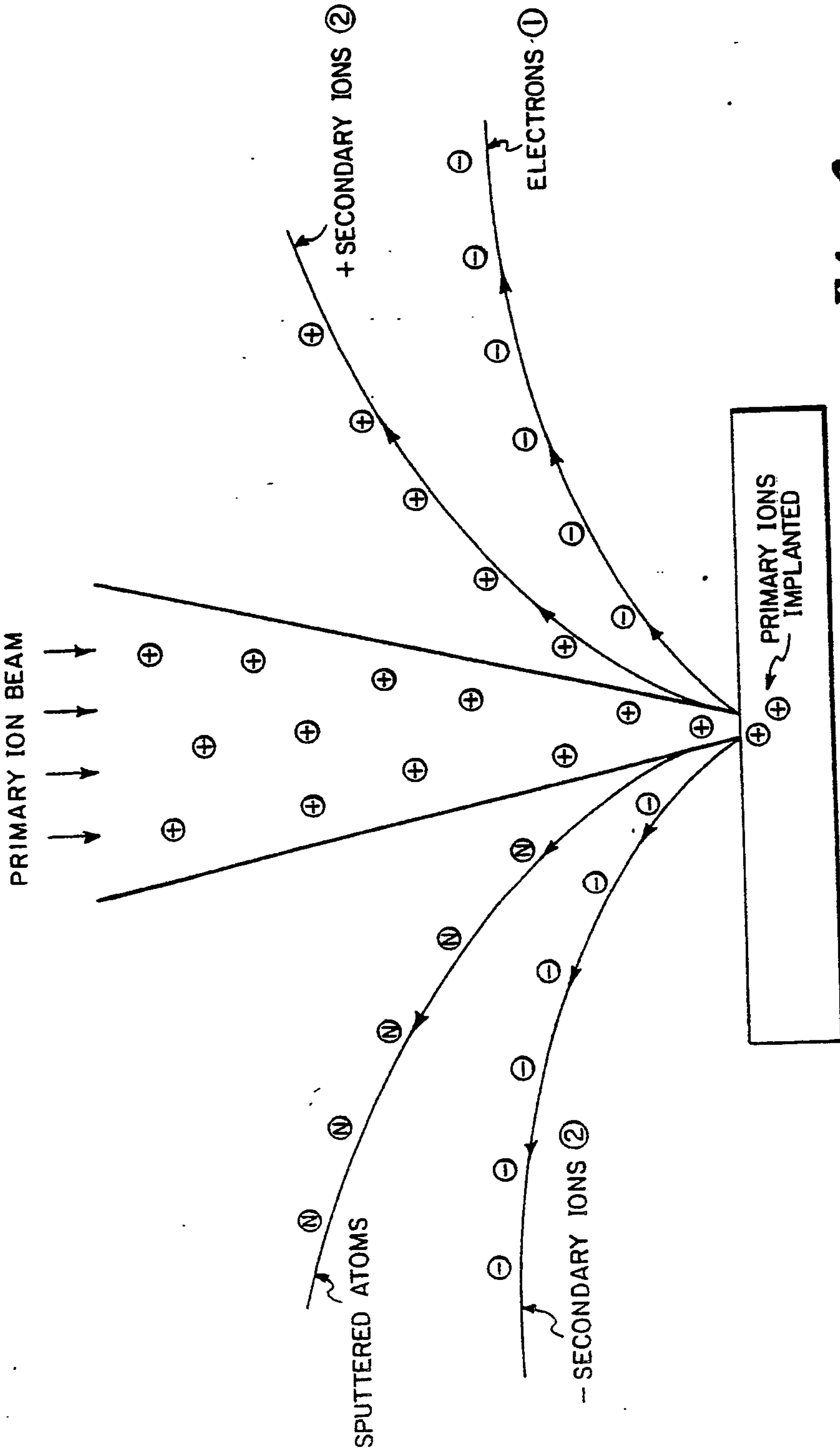
PRIMARY ION BEAM
+ SECONDARY IONS ②
ELECTRONS ①
PRIMARY IONS IMPLANTED
SPUTTERED ATOMS
– SECONDARY IONS ②

Fig. 2